Assimilation of Long-Range Lightning Data over the Pacific

Principal Investigator: Professor Steven Businger
Meteorology Department
University of Hawaii
2525 Correa Road
Honolulu, HI 96822 USA
Telephone: (808) 956-2569 Fax: (808) 956-877 email: businger@hawaii.edu

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Web Page http://www.soest.hawaii.edu/MET/Faculty/businger/projects/pacnet/

LONG-TERM GOALS

A Pacific Lightning Detection Network (PacNet) has recently been constructed with support from ONR and NASA. PacNet consists of five hybrid receivers, two sited in Hawaii, one in the Marshall Islands, one in the Aleutian Islands, and one to be installed on Christmas Island (Fig. 1). Together the PacNet sensors continuously monitor sferics over the central Pacific Ocean and adjacent land areas. The long term goals of this project are to continue development of PacNet and to support operational utilization of the data stream at NRL for (i) nowcasting convective activity, (ii) convective rainfall analyses over the Pacific, and (iii) to improve marine prediction of cyclogenesis and squall-line motion through sferics data assimilation in COAMP and NOGAPS. Technology transfer to NRL will be accomplished in close collaboration with NRL scientists, with data processing and analysis support from Vaisala and NASA scientists.

OBJECTIVES

The scientific and technical objectives of the Pacnet project are to collect long-range lightning data over the central and north Pacific Ocean, refine the relationship between lightning and rainfall rates and work toward implementation of operational assimilation of lightning derived products into numerical models.

APPROACH

Diabatic heating sources, especially latent heat release in deep convective clouds play an important role in storm development and dynamics. Lack of observations over the Pacific ocean can lead to inadequate initialization of the numerical models and large errors in storm central pressure and rainfall forecasts. Specifying diabatic heating sources in the early hours of the forecast can improve the model's performance. Data from Pacific Lightning Detection Network (PacNet) are used to identify the areas and intensities of convective activity and latent heat release in storms over the Pacific Ocean.

Our hypothesis is that in cases of cyclogenesis in marine air masses, including subtropical cyclogenesis, the relationship between rainfall and lightning rates will be relatively robust because the aerosol and cloud microphysical environment is more uniform. Results of our comparison of the lightning rate measured by PacNet and convective rainfall obtained from Aqua's and TRMM's microwave sensors for a variety of storm systems over the central north Pacific indicate that the ratio

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of lightning to rainfall rate shows a relatively stable relationship over the Pacific Ocean. This suggests that lightning data over the Pacific can be assimilated into numerical models as a proxy for latent heat release in deep convective clouds.

Personnel and their tasks for the Project

At UH, Professor Steven Businger, the PI, is working with Antti Pessi, PhD. Student, on the data assimilation. Kirt Squires, MS student is working on lightning in tropical cyclones. Duilia Mora, undergraduate student, is looking at climatology and distribution issues as a senior thesis topic.

Ken Cummins at Vaisala and Dennis Boccippio at NASA are using satellite and PacNet data to calibrate the network.

At the Navy Research Lab in Monterey, Dr. Allen Zhao and Dr. Melina Peng will undertake data assimilation studies. Dr. Joe Turk will investigate nowcasting applications of the lightning data stream over the Pacific.

WORK COMPLETED

Previously lightning data from PacNet were assimilated into MM5 using a lightning-rainfall-moisture profile relationship. The lightning-rainfall relationship was derived by comparing PacNet lightning data and simultaneous satellite rainfall data. FDDA (Four-Dimensional Data Assimilation) was used to assimilate lightning data into MM5. The model predicted vertical moisture profiles were nudged towards moisture values inferred from lightning data.

In a recent experiment, lightning data from PacNet were assimilated into MM5 using latent heating assimilation method (e.g., Manobianco et al., 1994). The method was implemented by modifying MM5 code. In particular the Kain-Fritch convective parameterization scheme was modified, and a lightning data input file was constructed. The method scales model's vertical latent heating profiles at each gridpoint and model level, depending on the ratio between model predicted rainfall and rainfall derived from the lightning data. Scaling is done only if the observed rainrate, derived from lightning, is greater than model predicted rainrate. To prevent too large latent heating values and model instability, the scaling coefficient was limited to three. If the observed rainrate was zero, no assimilation was done, as the absence of lightning does not imply the absence of rain. If the rainrate derived from lightning observations at any grid point was greater than zero, but the model rainrate was zero, a search algorithm was used. Initially the algorithm searches the adjacent model gridpoints with similar rainfall rate as observed. If no matching rainrate is found, further gridpoints are gradually included in the search until a match is found. The vertical latent heating profile from the matching gridpoint is used and the levels where the heating rate is positive are saturated.

The lightning data were assimilated the first eight hours of the 24-hour model simulation. The initial conditions were taken from GFS model and the boundary conditions were read every six hours. The method reads the input data file and nudges model’s tendency equations every model timestep (81 s).

The input file was created by relating lightning rate to rainfall rate. The lightning rates were computed over 1 x 1 degree squares centered at each grid point and over 30 minute time window centered at each timestep. The ratio of lightning to convective rainfall over the Pacific was determined by comparing the number of lightning strokes measured by PacNet, with convective rainfall obtained from Aqua's and TRMM's microwave sensors for a variety of storm systems (Pessi et al. 2004).

RESULTS

Preliminary results assimilating PacNet sferics data into MM5 show great promise (Pessi et al. 2005). Two cases were analyzed using the available long-range lightning data, a squall-line passage over Hawaii and a poorly forecast mid-latitude cyclone that approached the California coast. In the squall-line case, the data assimilation methods were able to correct the position of a squall line over Hawaii, which was forecast 150 km too far east in the control run. In the case study of the mid-latitude cyclone over the northeastern Pacific Ocean, a 12-hour MM5 control forecast showed a 10-mb error in the storm central pressure, whereas the error was reduced significantly when using lightning data assimilation methods.

Tropical Squall-line over Hawaii

A subtropical cyclone (kona low) impacted the Islands of Hawaii during the period 26-29 February 2004, causing heavy rain, thunderstorms, extensive flooding and two storm-related deaths. The MM5 6-hour precipitation forecast without lightning data shows a squall line over Oahu and Molokai (Fig. 2a). Lightning and satellite observations place the rainband ~200 km to the east. The forecast location of the squall line in the MM5 simulation with lightning data shows a much better match with observation (Fig. 2b).

Extratropical storm on the northeast Pacific

Beginning on 16 December 2002, an extratropical cyclone produced a large amount of lightning as it moved across the east Pacific Ocean. On December 18, the center of the storm was located near 43˚ N latitude and 135˚ W longitude, northeast of Hawaii and west of Oregon. Most of the lightning activity was associated with the cold front (Fig. 3).

Preliminary results for both the FDDA and latent heat nudging of MM5 are promising (Figs. 4 and 5), with the storm central sea-level pressure tracking much closer to the observations, when lightning data are assimilated. During the early hours of the control forecast the model does not produce any rain or the rain rates are very small. When we specified diabatic heating sources (latent heating) derived from lightning observations, using the lightning data assimilation method, the model's spin-up time was reduced and the production of rainfall started earlier in the forecast cycle. The intensity of the forecast storm, its position, and the rainfall distribution all more closely match the observations in the MM5 simulations that include lightning data (Figs. 4 and 5).

IMPACT/APPLICATIONS

A primary goal of the project is to assimilate the lightning data employing COAMPS[1] and 3-D variational data assimilation. Initial tests of two methods of data assimilation conducted at UH to investigate the impact of convective latent heating on forecasts of storm evolution are very promising. The early success of the methods holds promise for application in a variety of settings, including tropical cyclones.

In an operational forecast system, latent heat assimilation has some advantages over moisture profile assimilation (Table 1). Construction of the moisture profiles requires prior knowledge of the temperature, whereas latent heating scaling technique is independent of environmental temperature, making this approach more robust.

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[1] COAMPS – Coupled Ocean/Atmospheric Mesoscale Prediction System. http://128.160.23.41/Products/modeling/coamps

Table 1. Comparison of Lightning Data Assimilation Methods. Latent heating vs. FDDA

Latent Heating	FDDA
Lightning observations mapped to rainfall	Lightning observations mapped to rainfall-moisture profile
Modification of model equations and physics	No model modification – only input files
Model stability and physical issues: Assimilation to conv., non-conv. or combined?	FDDA relatively stable. Only a few adjustable parameters in a configuration file
Lots of tuning options by modifying model	Less tuning options by modifying configuration file
Improved storm central pressure forecast	Improved storm central pressure forecast

RELATED PROJECTS

NASA MSFC is in the process of validating the data using LIS on TRMM and conduct synoptic-seasonal-interannual studies of thunderstorms. The results of their work will have important implications for attaining our goals of operational data assimilation since the NASA results will provide a calibration of the PacNet network.

European VLF-Detector Network: The European Community has been actively developing a VLF lightning detection network in Europe. Contact has been made with one of the principals (Chris Kidd at the U of Birmingham, C.Kidd@bham.ac.uk) in that effort to facilitate synergy and scientific exchange.

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PUBLICATIONS

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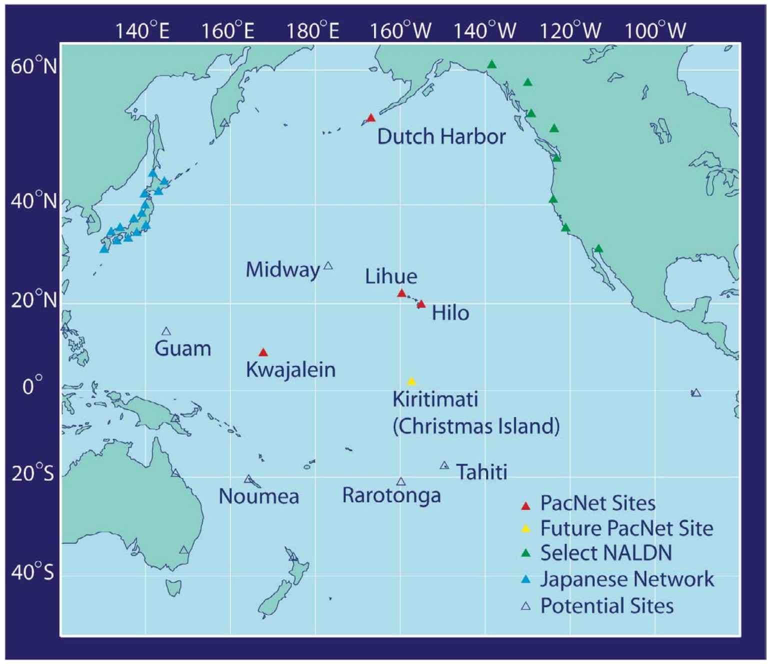

Fig. 1 PacNet's current and potential future sites for lightning detectors in the central Pacific. Data from detectors located in Japan and along the west coast of the U.S. are available in the processing stream received at the Vaisala Thunderstorm Unit to complement the PacNet data.

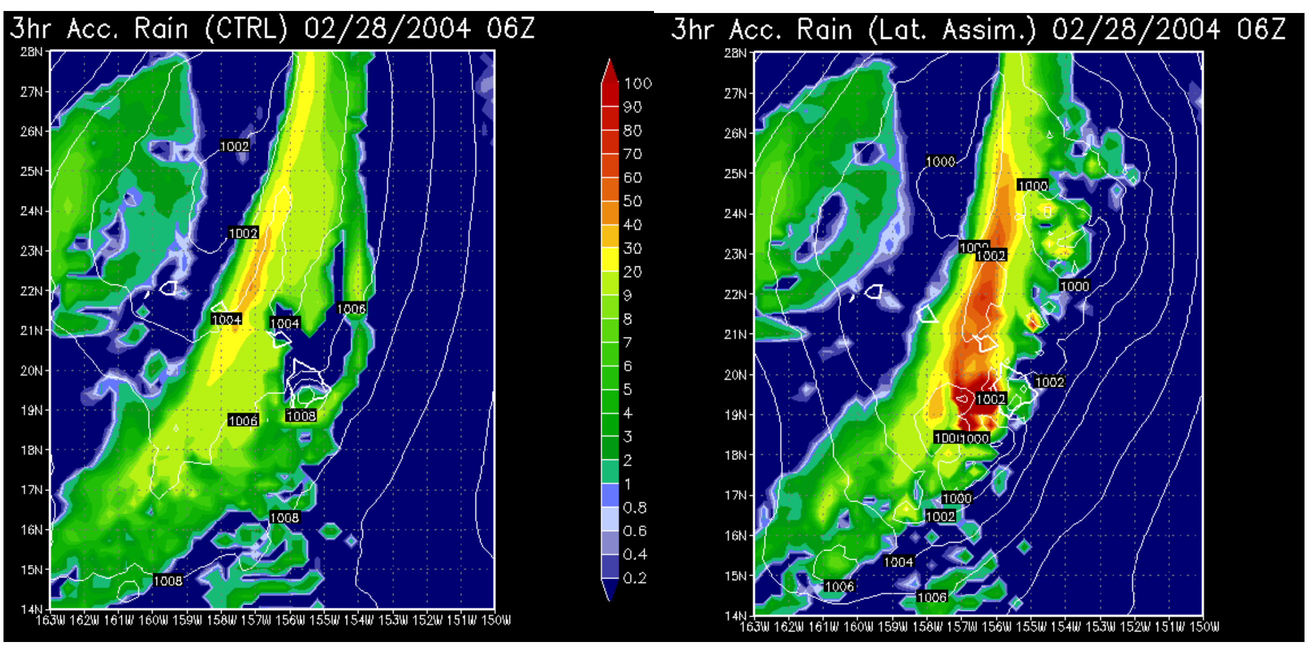

Fig. 2 a) MM5 6-hr forecast without lightning data of precipitation (shading) and sea-level pressure (contours) valid at 0600 UTC on 28 February 2004.
b) MM5 6-hr forecast with lightning data.

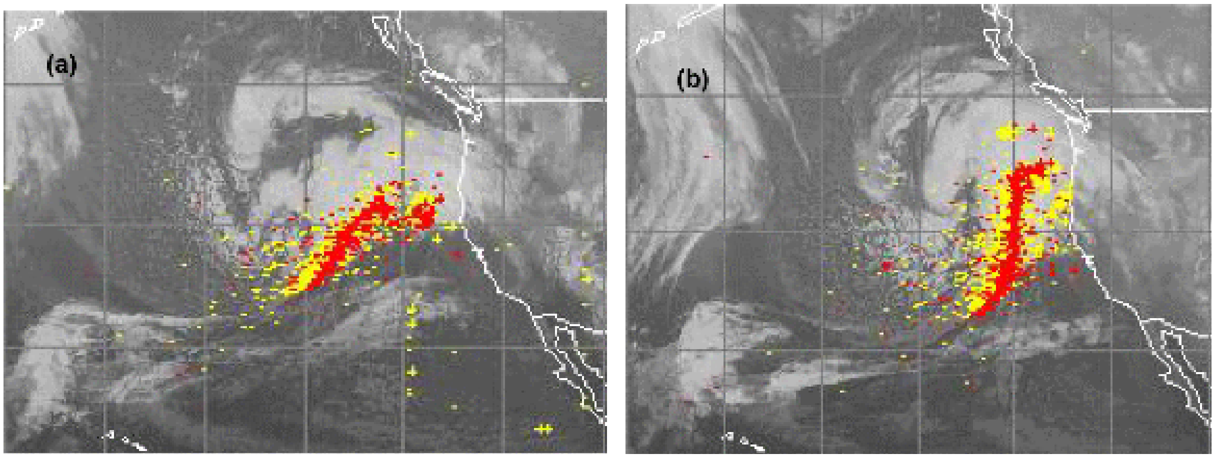

Fig. 3 (a) Satellite image at 1800 UTC on 18 December 2002 and (b) 0300 UTC December 19 (right). ILRN Lightning detected between 1453 and 1753 UTC and 2353 and 0253 UTC December 18-19 (right). Red dots indicate lightning during the last hour and yellow dots during the previous two hours.

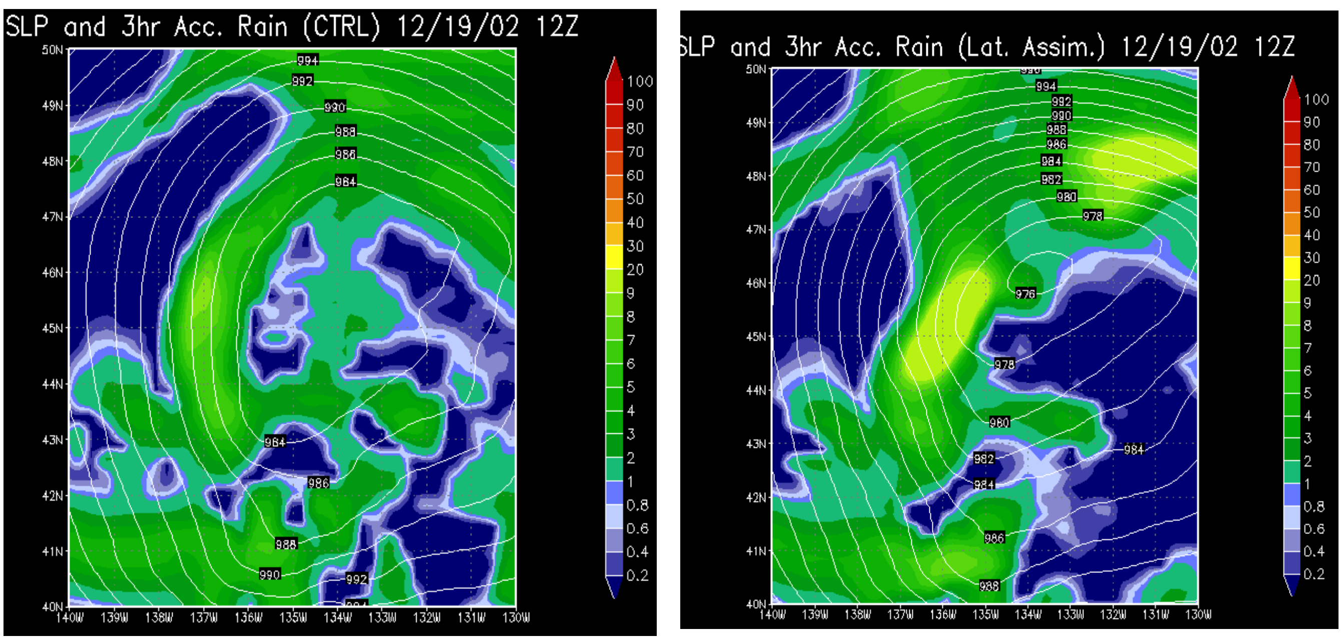

Fig. 4 Twelve-hour forecast of sea-level pressure and 3-hr accumulated rainfall over the eastern North Pacific Ocean valid at 1200 UTC on 19 December 2002, without and with lightning data assimilation (left and right panel, respectively) (Pessi et al. 2005).

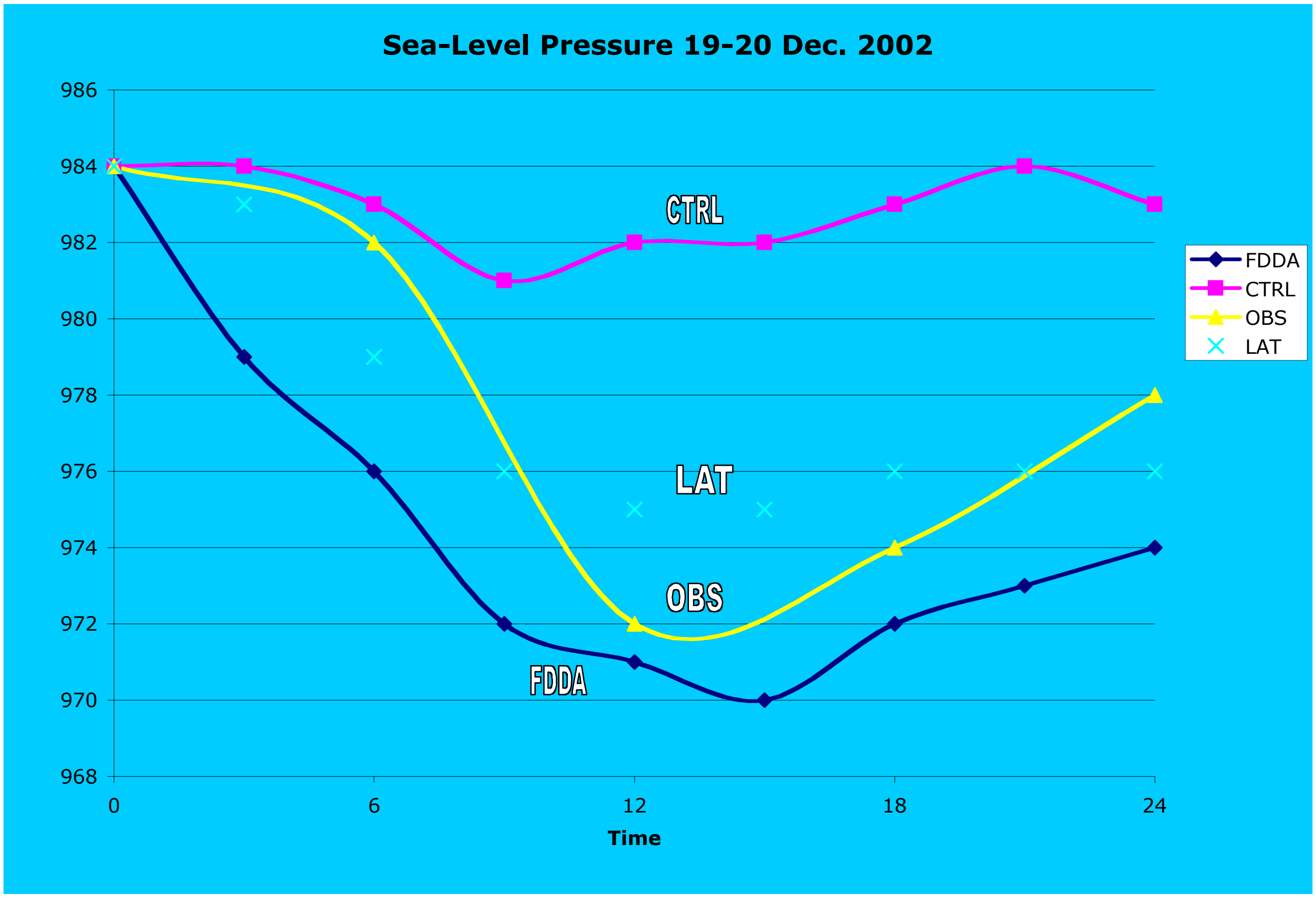

Fig. 5 Comparison of observed storm central pressure (yellow) with that predicted by MM5 on 19 December 2002 with (white and blue) and without (purple) lightning data (Pessi et al. 2005).